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Jeff C. Schank

*University of Nebraska-Lincoln*

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THE BRAIN: PHYSIOLOGICAL FOUNDATIONS  
OF EVALUATION AND MEMORY

JEFF C. SCHANK

Department of Philosophy  
University of Nebraska—Lincoln  
Lincoln, Nebraska 68588

Behavioristic axiomatizations of human evaluation have been well established (von Newmann and Morgenstern, 1953; Leinfellner, 1969). The axiomatization of the evaluative interpretation scheme can be applied to the historical sciences and provides a model of historical time. Newtonian time can be defined by imposing a strict serial order on temporal events by means of the relations of simultaneity and succession, which has been axiomatized recently (Leinfellner, 1966). The former axiomatization of the structure of evaluation can be combined with the latter axiomatization of the structure of temporally ordered memory, based on preference and indifference relations of an individual as he evaluates past events or future possible events. The author's intention is to go a step further and incorporate the organization of the brain as foundations of memory time and evaluation. In recent publications, Pribram (1976) showed that the organization of the brain fulfills the requirements of the von Newmann and Morgenstern axiomatization of evaluation. Further, research has shown that memory is correlated with certain biochemical changes in the brain. In short, we obtain a new solution for the mind-body problem with respect to evaluative behavior and decision-making, especially with respect to evaluation of an individual's history.

† † †

INTRODUCTION

When considering an individual's history, the historical and, in general, the social sciences have asked why events of an individual's history occurred (Leinfellner, 1973). This problem has been approached by a strict causal or deterministic ordering of events, objects, and actions from past to future as sufficient for an explanation of a person's history. But problems arise with this approach to an individual's history. For example:

A person learns a language ( $a_e$ ) in anticipation of the prospect of immigrating in the near future to the country where this language is spoken. In such a case he will evaluate learning this language very highly according to an activist's attitude. But if this same individual after arriving in this new country becomes involved in an

accident, he may devalue this same act of the past ( $a_e$ ) after he has experienced all the troubles which were consequences of the accident (Leinfellner, 1973).

This example illustrates the importance of evaluation in a person's history, while also illustrating the inadequacy of causal or deterministic orderings of events as an explanation of a person's history. Therefore, instead of asking why events of an individual's history occurred, we should ask why an individual evaluated an event in a particular way.

In this paper, evidence from brain research is used to develop foundations for behavioristic axiomatizations of evaluation and memory time (i.e., those events which are represented in the brain and temporally ordered). If the organization of the brain fulfills the requirements of the axiomatizations of evaluation and memory time, then there are inbuilt orientation schemata which are called value spaces for value orientation and individual decision-making, and memory spaces for time orientation. Both value and memory spaces can be combined to form an orientation scheme which is called historical time for evaluation of past events (retrospects) or future possible events (prospects). In short, I will show that the organization of the brain fulfills the axiomatizations of evaluation and memory time which can be combined to define one of the more common spaces human beings evaluate and make decisions about with respect to their individual histories.

In order to show that historical time is an innate space for evaluation and decision-making with regard to the past or future of an individual, I will, for simplicity, separately develop the brain foundations for the axiomatization of evaluation and then the axiomatization of memory time. But first, I will examine what a space is, and how the axiomatizations of evaluation, memory time, and evaluation and memory time combined (historical time) satisfy the requirements of a space.

Leinfellner (unpublished) outlined the fundamental assumptions which every adequate definition of a space should fulfill.

***Fundamental assumptions about spaces:***

1. A space should be describable by empirically valid statements called empirical spatial descriptions which belong to an empirical language.

2. A space should be either the intuitive order or the abstract conceptual form of (1) and may be called the order function of spaces.

3. A space should be definable as a system of mathematical or abstract objects with relations defined between them. This is the structural conception of spaces described by a theoretical language.

4. A space should be a two-fold system of subsystems. There are in most cases three subsystems consisting of "an empirical space" having a recognizable intuitive order, capable of an abstract definition.

***Definition of a space:*** A space can be defined as any system of subsystems, or any system of representation, if it is a basic or epistemological structure and if:

5. At least one structural description is empirical.

6. At least one of the relations  $R_i$  is at least a quasi series founding relation and one  $R_j$ , where  $i = j$  and  $1 \geq i$ ,  $j \geq 1$  is an identity relation.

7. At least one of the representation functions is a measurement function.

Therefore, the structures of evaluation and memory time, defined axiomatically, are value and memory spaces respectively if and only if the following conditions are fulfilled: First, the axiomatic definitions of evaluation and memory time must fulfill the definition of a space and parts (2) and (3) of the fundamental assumptions about spaces. Second, the interpretations of the axioms defining evaluation and memory time must fulfill parts (1) and (4) of the fundamental assumptions about spaces. The axiomatizations of evaluation and memory time satisfy the requirements of a space; thus historical time, defined by a combined axiomatization of evaluation and memory time, satisfies the requirements of a space (Leinfellner, 1973 and unpublished).

**BRAIN FUNCTION: A TWO-PROCESS MECHANISM**

Before developing the brain's physiological foundations of evaluation and memory time, it will be useful to briefly

examine Pribram's systems approach to brain function. This approach assumes two basic processes, i.e., operators (nerve impulses) and states (neuroelectric). Classically, the neuron has been viewed as the sole organizer of the nervous system, but Sherrington's (1906) work with the complexities of the reflex demonstrated the importance of the properties of the synapse (e.g., the slow potential microstructure). The distinction between nerve impulses and graded slow potentials is stated succinctly by Pribram (1971):

The present emphasis is on the slow potentials themselves; the suggestion is that the slow potentials produce patterns which serve a function in addition to a role in impulse transmission: the view taken here is that the slow potential pattern "computes" both the spatial neighborhood interactions among neural elements and, to some extent, the temporal interactions over a range of sites by a continuous (analogue) rather than a discrete, all-or-none (digital) mechanism (Pribram, 1971).

Moreover, Pribram and Gill (1976) have outlined the basic logic of the two-process mechanism of brain function:

The most generally known innovation in control theory has been the formal description of the concept of feedback (e.g., see Miller, Galanter and Pribram, 1960), a circular process initiated by a test, a matching of two settings. When there is a mismatch, one of the settings becomes fixed while the other triggers an operation which continues until a match is produced. Thus a test-operate-test-exist sequence, a TOTE, characterizes the feedback: for example, if the setting of a thermostat and that of room temperature are incongruent, i.e. mismatch, a furnace is either turned on or off until congruence is established.

More recently, another, equally useful conception, feedforward (e.g., see Pribram, 1971) has been found important. In feedforward control, an operation proceeds to a predetermined end point. For example, in most apartments, the furnace continues to operate for fixed periods, irrespective of local temperature conditions (Pribram and Gill, 1976).

**BRAIN MECHANISMS OF A VALUE SPACE**

Since my purpose in this section is to develop the neurological foundations of a value space, only a limited set of axioms (Leinfellner, unpublished) will be considered for simplicity (for a complete set of axioms, see Leinfellner, 1969). The set of axioms is divided into three groups: mixture, order, and measurement.

$\langle X, P; \succ, \sim \rangle$  defines the structure of evaluation (V) if and only if the following conditions are fulfilled.

**Axiom 1.** For any tuple  $(x_1, x_2, \dots, x_n)$  to which  $p_1, p_2, \dots, p_n$  can be adjoined, where  $P(e_1) = p_1, P(e_2) = p_2, \dots, P(e_n) = p_n$  and  $0 \leq P(e_i) \leq 1$  and for which  $\sum_{i=1}^n p_i = 1$ , the mixture of  $x_1, x_2, \dots, x_n$  with probabilities  $p_1, p_2, \dots, p_n$  denoted by  $(p_1 x_1, p_2 x_2, \dots, p_n x_n)$  is a uniquely defined element of  $V$ .

**Interpretation:** A value  $x_i$  is ascribed by a person under certain conditions at a time,  $t$ , to objects, actions, and events  $a_i$  which indicates a relative place  $x_i$  the object possesses within the ranking order  $x_1, x_2, \dots, x_n$ . Thus, if an individual can adduce the appropriate probabilities  $p_1, p_2, \dots, p_n$ , he can also match the probabilities with the values.

We need to assume that human beings as well as higher animals have an innate tendency to improve and refine-evaluation judgments (Leinfellner, unpublished). This assumption is needed because it explains and justifies an important characteristic of a value space, i.e., to be a mixture space. A mixture space involves the use of probability by an individual in refining evaluations. Since human beings are able to sharpen and refine evaluations, each justification of evaluation is a justification of probability, and thus evaluation and probability are mutually interdependent and subjective.

Pribram (1976) has taken the first step towards the development of the brain mechanisms for evaluation, i.e., by showing a basis in the brain for the axiomatization of evaluation by von Neumann and Morgenstern (1953). Although similar to the axiomatization presented here, their axiomatization is not complete. Nevertheless, much of the development of the neurological foundations of von Neumann and Morgenstern's utility theory is applicable to the axiomatization of evaluation presented here.

Values (Pribram, 1976) are expressed by need-satisfying behaviors. In other words, values have their basis in biological needs; a quantification of internal controls over behavior leading to the satisfaction of biological needs. The mechanisms which control biological needs can be classified into three major categories. The first mechanism regulates the amount of appropriate behavior engaged in, and is called the satiety mechanism. A second mechanism readies the individual to behave in a particular manner and initiates the appropriate behavior. The third mechanism coordinates the other two mechanisms into a smoothly running system.

The *satiety* mechanism is organized by a closed-looped feedback process. Research (Pribram and Bagshaw, 1953) showed that monkeys with a removed amygdala failed to have a cutoff point beyond which they would refuse non-preferred objects, while unoperated monkeys did have a cutoff point. This indicated that the amygdala controls the amount of behavior that satisfies a biological need once it is initiated.

The *readiness* mechanism is organized by a helical-loop feed-forward process, operating similar to a dial on a thermostat. This mechanism processes information because alternatives are involved, e.g., the dial setting of a thermostat involves the alternatives "off" and "on." Research (Anand and Brobeck, 1952) has shown that rats with a damaged far-lateral hypothalamus starved to death. This suggested that the far-lateral hypothalamus controls the amount of behavior that is initiated. The *coordination* mechanism shifts control from the feedback to the feedforward process. Anand (1963) showed that the satiety and the readiness mechanisms for feeding are reciprocally coupled. His experiments showed that when the satiety mechanism was active the readiness mechanism was inhibited.

Furthermore, probabilities are an individual's estimate of the likelihood that the occurrence of particular behaviors will satisfy particular needs. Research has demonstrated a mechanism which estimates the probability that the occurrence of a particular need-satisfying behavior will satisfy a biological need. Evidence supporting a probability estimating mechanism comes from monkeys with resected frontal lobes. These monkeys were unable to distribute their responses probabilistically from prior experiences, as do non-resected monkeys (Pribram, 1961). Moreover, for the axiomatization of evaluation discussed here, we must show that the amount of needs and desires, and the estimate of probability, are multiplicatively related and mutually interdependent. Pribram (1976) supported a multiplicative relation between values and probabilities by the close link between the brain systems regulating values and the brain systems involved in probability estimation. This close link, both anatomically and functionally, of these brain systems also indicates their mutual interdependence.

**Axiom 2.** The subspace  $(V, \succ, \sim)$  is quasi-ordered.

**Interpretation:** " $V$ " is the set of values; " $\succ$ " is the preference relation; " $\sim$ " is the indifference relation.

Brain mechanisms involved in establishing preferences have been shown to be separate from those regulating the satisfaction of biological needs and the estimation of probability (Pribram, 1976). Pribram (1969) showed that removal of areas remote from those mechanisms involved in need-satisfaction and the estimation of probability interfere with discrimination of choices between cues. This discrimination of choices has been shown (Irwin, 1958) to indicate preferences. Preferences are then dependent on a mechanism which involves the ability to discriminate between situations that lead to satisfaction, and thus are situation dependent, reflecting the invariant properties of the situation. Therefore, the use of "signs" is required, i.e., the mechanism by which preferences become organized. "Signs are made and recognized when motor mechanisms operate on the junctional patterns initiated by input. . . . Signs become communicative acts that remain

invariant over a large variety of contexts. . . .” (Pribram, 1971).

**Axiom 3.** If  $x_i \succ x_j \succ x_k$ , there exists a  $p$  such that  $x_j \sim (px_i, (1 - p)x_k)$ . **Interpretation:** If an individual reveals his preferences in the following manner:  $P(a_i, a_j)$  and  $P(a_j, a_k)$  where  $(\succ/P)$ , and if one is indifferent between a mixture  $(px_i, (1 - p)x_k)$  and  $x_j$ , the probability,  $p$ , indicates the relative interval:  $x_k - x_j/x_k - x_i$ .

This axiom, if empirically valid, entails linear transformational properties and makes a value space into a measurement space. The mixture of need-satisfying behavior must be measurable by at least an ordinal scale and at most an interval scale. Pribram (1976) proposed that values are measurable in terms of the amount of behavior needed in their satisfaction, provided a “zero” point is agreed upon.

These axioms, based on the organization of the brain, show that a value space is an innate mechanism of value orientation and individual decision-making. It is not assumed that the evaluator is an idealized figure with unlimited logical faculties and computational capacities. In individual decision-making, computation requires the use of a finite number of symbols or tokens in describing events of one’s environment. Pribram (1971) has described how symbols develop:

These develop when the brain’s motor mechanisms become engaged in perception and feeling. The resulting coding operations construct signs and symbols . . . symbols, when motor mechanisms operate on junctional core-brain receptive processes. . . . Symbol communication almost completely depends on the context in which symbols occur. (Pribram, 1971).

### BRAIN MECHANISMS OF A MEMORY SPACE

A memory space is defined by an order axiom which demands some minimal properties for establishing a temporal order of memory by the relations of simultaneity and succession. Leinfellner (1966) axiomatized serial time which we now apply to memory time.

$\langle M; \succ, = \rangle$  defines the structure of a temporal memory order.

**Axiom 4.** 3.1 For any  $m_1 \in M$ ,  $m_1 = m_1$ ; 3.2 For any  $m_1, m_2 \in M$ , if  $m_1 = m_2$ , then  $m_2 = m_1$ ; 3.3 For any  $m_1, m_2, m_3 \in M$ , if  $m_1 = m_2$  and  $m_2 = m_3$ , then  $m_1 = m_3$ ; 3.4 For any  $m_1, m_2 \in M$ , if  $m_1 \succ m_2$ , then not  $(m_2 \succ m_1)$ ; 3.5 For any  $m_1, m_2, m_3 \in M$ , then not  $(m_1 = m_2)$  if and only if  $m_1 \succ$

$m_2$  or  $m_2 \succ m_1$ . **Interpretation:** “ $M$ ” is a set of memories stored in the brain; “ $\succ$ ” is the succession relation; “ $=$ ” is the simultaneity relation.

To demonstrate a neurological basis for a memory space, there should be brain mechanisms satisfying the following requirements: (a) external stimuli must be encoded into neural representations, (b) neural representations of external stimuli must be stored, (c) it must be possible to retrieve specific stored experiences, (d) retrieved information must be decoded into a state which recreates the original experience, (e) it must be possible to recognize external stimuli from previously stored experiences, and (f) memories must be ordered in the brain.

Coding operations of external stimuli take place in the nervous system when physical energy is sensed by receptors and transformed into nerve impulses. When nerve impulses reach synaptic networks, the discrete signals become encoded in the slow potential microstructure (Pribram, 1971). Two classes of codes are involved; i.e., codes involving nerve impulses and codes involving slow potentials. Impulse coding uses both temporal and spatial codes, and are “read” by a mechanism in the central nervous system. This readout of the impulse-coded messages takes place in the neural junctions, in the production of slow potential microstructure, resulting in momentary states. Further, two classes of transfer functions are employed by the readout mechanism. Some transfer functions allow reversibility, i.e., a one-to-one mapping between ciphers of a code. Other transfer functions are irreversible unless a key exists to decipher a code, e.g., the alphabet.

It is a characteristic of states that they are modifiable. Therefore, permanent modifiability of coded neural representations should be possible. The process of chemical induction has been proposed as a model of permanent memory storage. The process of neural induction is similar to the process that takes place during embryological development of an organism. The relation between inductor and substrate is stated by Pribram (1971):

1. Inductors evoke and organize the genetic potential of the organism.
2. Inductors are relatively specific as to the character they evoke but are relatively non-specific relative to individuals and tissues.
3. Inductors determine the broad outlines of the induced character; details are specified by action of the substrate.
4. Inductors do not just trigger development; they are a special class of stimuli.
5. Inductors must be in contact with their substrate in order to be effective; however, mere contact is insufficient to produce the effect—the tissue must be ready, must be competent to react.

6. Induction usually proceeds by a two-way interaction, by a chemical conversation between inductor and substrate (Pribram, 1971).

Neural induction is initiated by intermediate memory mechanisms. Excitation of nerves starts the production of neural RNA which induces configurational changes by chemical "conversations." These chemical conversations are reversible and can fade, unless maintained by repetition of the same pattern.

In the brain, neural induction accomplishes permanent modifiability of neural tissue in three ways (Pribram, 1971). Hydén (1976) outlined a mechanism of chemical storage. When an individual learns a sufficiently difficult task, a short-lasting production of protein starts, and involves at least two proteins; one is called the S100 protein. Further, at least two other proteins are synthesized in the membranes of the synapses. These long lasting nerve cell changes involve protein molecular changes which become inscribed in a certain pattern into the membrane of millions of neurons. Another mode of modifiability is *neural growth*. Neurons have growth cones which, if given an open path, elongate the nerve fiber tip. Evidence (Rose, Malis, and Baker, 1961) showed that neural growth is possible and appears to be enhanced by a rich experience (Bennett, Diamond, Krech, and Rosenzweig, 1964). Finally, *neuroglia* plays a role in neural modifiability. It may be that oligodendroglia direct the growth cones of neurons. Evidence from the peripheral nervous system showed that Schwann cells, a close relative of glia, guide the direction of the growth of nerve fibers that regenerate after injury. In short, any of the three basic modes of neural modifiability are registered as a change in the microstructure of junctional slow potential activity.

We now turn to the problem of how it is possible to recall and to recognize specific information and decode it into a state which recreates the original experience. In order to accomplish this, there should be an organizing process which allows stored information to be decoded into an experience that recreates the original experience. Pribram (1971) proposed that the junctional microstructure of slow potentials provides this organization. He derived a model of neural organization from the optical process of holography.

A neural holographic mechanism of information storage rests on two assumptions: First, neural representations of input are not photographic, but consist initially of a set of feature detectors and a set of transformations similar to those for the optical process of holography. Neural holographic images result from interference patterns; i.e., when arrival patterns converge from at least two sources their designs produce interference (conveniently viewed in wave-mechanical terms). Second, assume that these interference patterns of postsynaptic patterns are coordinate with awareness. It then

follows that information is distributed over the entire extent of the neural pattern similar to that of a physical hologram. Nevertheless, a major difficulty with a neural holographic mechanism arises; i.e., "brain waves" as presently recorded are insufficient for a significant interference pattern, since brain waves carry only a small amount of information (Pribram, 1971).

With a neural holographic mechanism of information storage, we can detail the mechanisms of recall and recognition. The mechanism of recall involves a feedforward process, while recognition is a content-addressable feedback mechanism. During recall, a stimulating event triggers a short-term memory mechanism. Retrieval requires simply the repetition of the pattern or essential features of it which originally induced storage resulting in an interference pattern of the junctional slow potential microstructure which recreates the original experience. On the other hand, during recognition short-term memory is often not involved; images can be reconstructed even from input that only partially replicates stored information. Juxtaposition of input and long-term memory is entailed in recognition; a best fit is quickly attained through cross-correlations among simultaneously occurring and interfering wave fronts of slow potentials. A neural holographic process of recall and recognition has the advantage of doing away with the need for keeping track of where information is stored, because content can be recalled or recognized without reference to location.

Memory, however, also tells us in which direction we move through time; we remember the past but not the future. Then, somehow, memory is temporally ordered. A directed graph model of memory storage would impose a temporal order or directional order to memory engrams, fulfilling the axiomatization of memory time, since directed graph models can be mapped onto set-theoretical models (Harary, Norman, and Cartright, 1965). Engrams would not be required to have a particular location in the brain; all that is required is a directional ordering of engrams. Lashley (1958) proposed that tonic activity (neuroelectric states) provides memory storage with its directional character:

The background of tonic activity would determine the direction of attention and of the flow of thought, restricting it to related associations. It would provide the binding force that holds together the temporal sequences through memory span, and more permanent associations (Lashley, 1958).

Now we can make the following conjecture: the directional character of memory is imposed by the junctional microstructure of slow potentials, conveniently viewed by a directed graph model. A directed graph model of memory storage is compatible with existing evidence and with a neural holographic process.

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